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Design of a TEM Waveguide for Ultra-Wideband Applications

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1. INTRODUCTION

Impulse launching and receiving antennas are required for ultra-wideband applications involving high-fidelity transmitting and sensing of impulse electromagnetic fields. Due to their dispersive characteristics conventional wideband antennas, such as log-periodic arrays, spiral antennas, and ridged horn type antennas, perform poorly as high-fidelity antennas for wideband impulsive waveforms. However, a TEM horn forms a natural structure for low-dispersion launching and receiving of ultra-wideband impulses. [1]

Many systems require TEM horns that operate in an environment where the lateral sides of the horn must be conducting material. Such horns thus have only one open surface and special measures must be taken to ensure the TEM characteristic. A candidate structure that satisfies this requirement can be derived from a flared waveguide with a conducting septum. But solutions for such structures are not readily available and the development of a design methodology is therefore difficult. To facilitate design, we have chosen to increase our understanding of the behavior of wave propagation in rectangular waveguide with septum, then flared waveguide with septum, and ultimately a flared rectangular horn with septum.

In this presentation, we present the propagation characteristics of a rectangular waveguide with septum. Derivatives of this structure will ultimately be used to form laterally closed TEM horn antennas. Postulating that onset of non-TEM modes will limit bandwidth, we will first present the cutoff wavelengths of the lower order modes for different septum widths and heights. Then we will depict a waveguide impedance as a function of the same variables for the parameter ranges where only TEM mode propagates and begin the accumulation of data that can ultimately be used in the design process.

2. PROBLEM DESCRIPTION

A rectangular waveguide with an internal septum is illustrated in Fig. 1. The zero thickness septum of width t is located at a height h in an infinitely long

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rectangular waveguide of dimensions a and b. The Green function method was employed in the analysis [2] and the results were verified using HFSS, a finite element package from Ansoft.

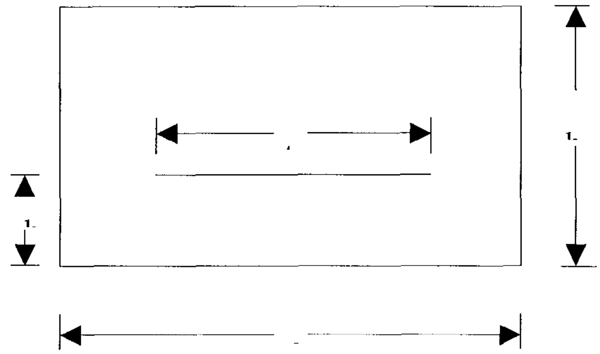

Fig. 1. Rectangular waveguide with septum

3. RESULTS

Cutoff wavelength and bandwidth

During the design of an ultra-widebandwidth component, it is necessary to estimate its bandwidth, where the bandwidth will be limited by the onset of the first non-TEM mode. The lowest non-TEM mode in an empty, rectangular waveguide is TE_{10} with a > b. The simulation results show, as expected from the field equations [3],

$$E_x \sim \cos\frac{m\pi x}{a}\sin\frac{n\pi y}{b}$$

$$E_y \sim \sin\frac{m\pi x}{a}\cos\frac{n\pi y}{b}$$

that there is no change of the cutoff wavelength of TE_{10} mode when the septum is introduced. We will therefore use that cutoff as the basis of our investigation of bandwidth. Furthermore, simulations have also shown that the cutoff wavelengths for the TE_{01} and TE_{11} modes in a conventional waveguide ($b/a = 0.5$) with septum are always greater than the respective cutoffs in a waveguide without septums as shown in Figures 2 and 3.

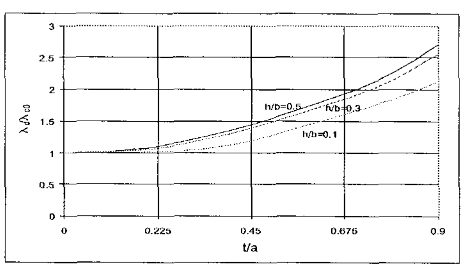

Fig. 2. The cutoff wavelength of TE_{01} with septum normalized to the cutoff wavelength of TE_{01} without septum versus normalized septum width.

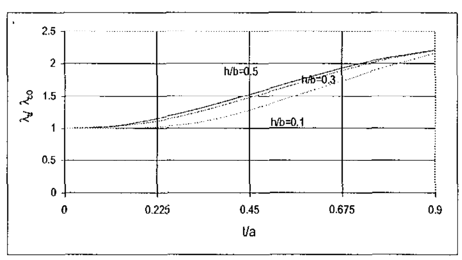

Fig. 3. The cutoff wavelength of TE_{11} with septum normalized to the cutoff wavelength of TE_{11} without septum versus normalized septum width.

Figures 2 and 3 show the ratio of cutoff wavelength with spectrum to the cutoff wavelength without spectrum for the TE_{01} and TE_{11} modes versus the normalized septum width *t/a* for different normalized septum height *h/*b.

The question then arises as to the conditions under which the cutoff wavelengths for the TE_{01} and TE_{11} modes can exceed that for the TE_{10} mode, i.e., the conditions under which the TE_{10} is the lowest order mode and is the determinant of the bandwidth. Fig. 4 and Fig. 5 exhibit the ratio the cutoff wavelength of TE_{01} and TE_{11} modes to that for the TE_{10} mode for a conventional waveguide (*b/a=0.5*) with septum. The variable is normalized septum width and normalized septum height is a parameter.

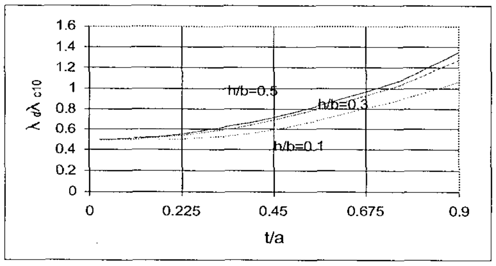

Fig. 4. The cutoff wavelength of TE_{01} mode with septum normalized to the cutoff wavelength of TE_{10} mode versus normalized septum width.

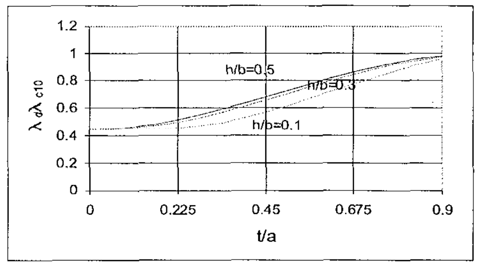

Fig. 5. The cutoff wavelength of TE_{11} mode with septum normalized to the cutoff wavelength of TE_{10} mode versus normalized septum width.

Figure 4 shows that the cutoff wavelength of TE_{01} mode will be longer than the cutoff wavelength of TE_{10} mode for *t/a* greater than 0.675, i.e., that the TE_{01} mode will replace the TE_{10} mode as the lowest non-TEM mode for *t/a* greater than 0.675 thus reducing the bandwidth of the component. Figure 5 provides evidence that the cutoff wavelength for the TE_{11} mode will be shorter that the cutoff wavelength of TE_{10} mode as long as we keep the normalized septum width *t/a* less than 0.9. So, for $t/a < 0.675$, only the onset of the TE_{10} mode need be a concern.

Waveguide Impedance

The waveguide impedance is defined as [4], [5]

$$Z_{pv} = \frac{V^2_{\max}}{2\overline{P}} \,,$$

with $V_{max} = \int \vec{E} \cdot d\vec{l}$, the voltage between the septum and wall, and

$\overline{P} = \frac{1}{2}\int_0^b \int_0^a E_y H_x dydx$, the average power through the waveguide cross section.

For single mode operation, we only care about the waveguide impedance of the TEM mode, which happens to be independent of the frequency. In Figure 6 we show the TEM mode waveguide impedance versus normalized septum width t/a for different normalized heights h/b. This plot shows that the waveguide impedance increases as h increases. It is also shows that the waveguide impedance decreases as the septum width increases. The impedance of the parallel plate waveguide can interpret these phenomena since

$$Z \sim \frac{h}{t}$$

If we choose t/a and h/b judiciously, the component will exhibit some ultra-widebandwidth characteristics.

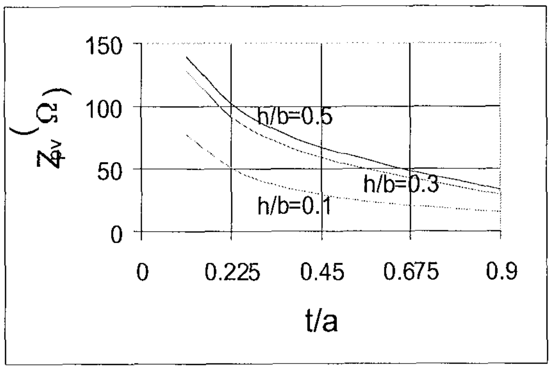

Fig. 6. The waveguide impedance versus normalized septum width t/a.

4. CONCLUSION

Green's function and finite element methods were used to investigate the characterístics of a conventional rectangular waveguide with an enclosed septum. Conditions were determined which would guarantee single mode, TEM operation. A waveguide impedance for this mode of operation, which is frequency independent and possesses the characteristics of the conventional transmission line impedance, was defined and computed for a range of variables. Such devices will find utility in ultra-wideband systems. Furthermore, they are being used as the starting point for a development of novel UWB radiators.

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